

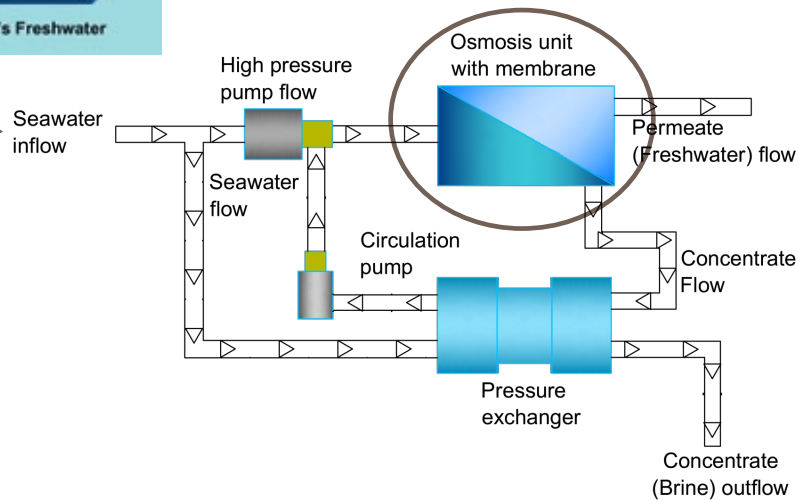
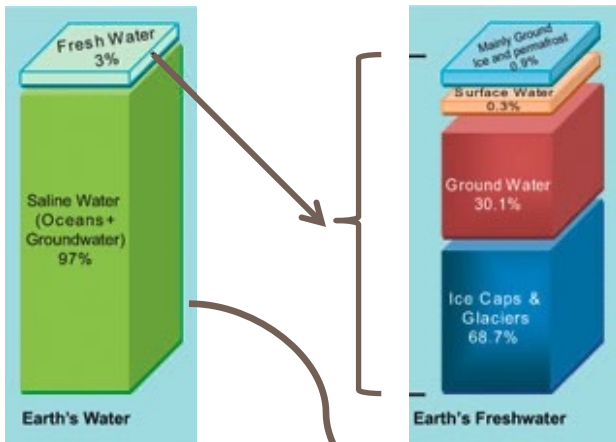
# Optimal Planning and Design of Seawater Reverse Osmosis Plants. A Holistic Approach



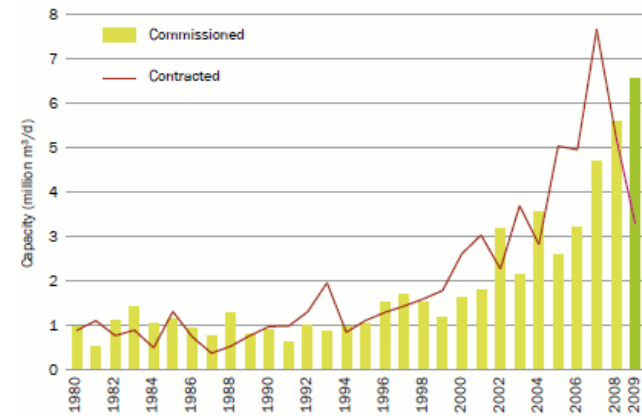
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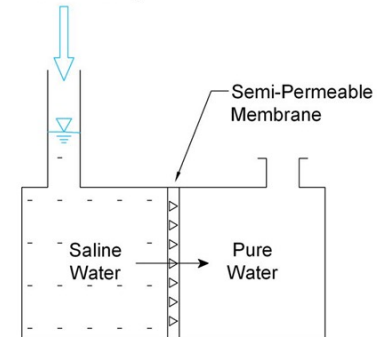


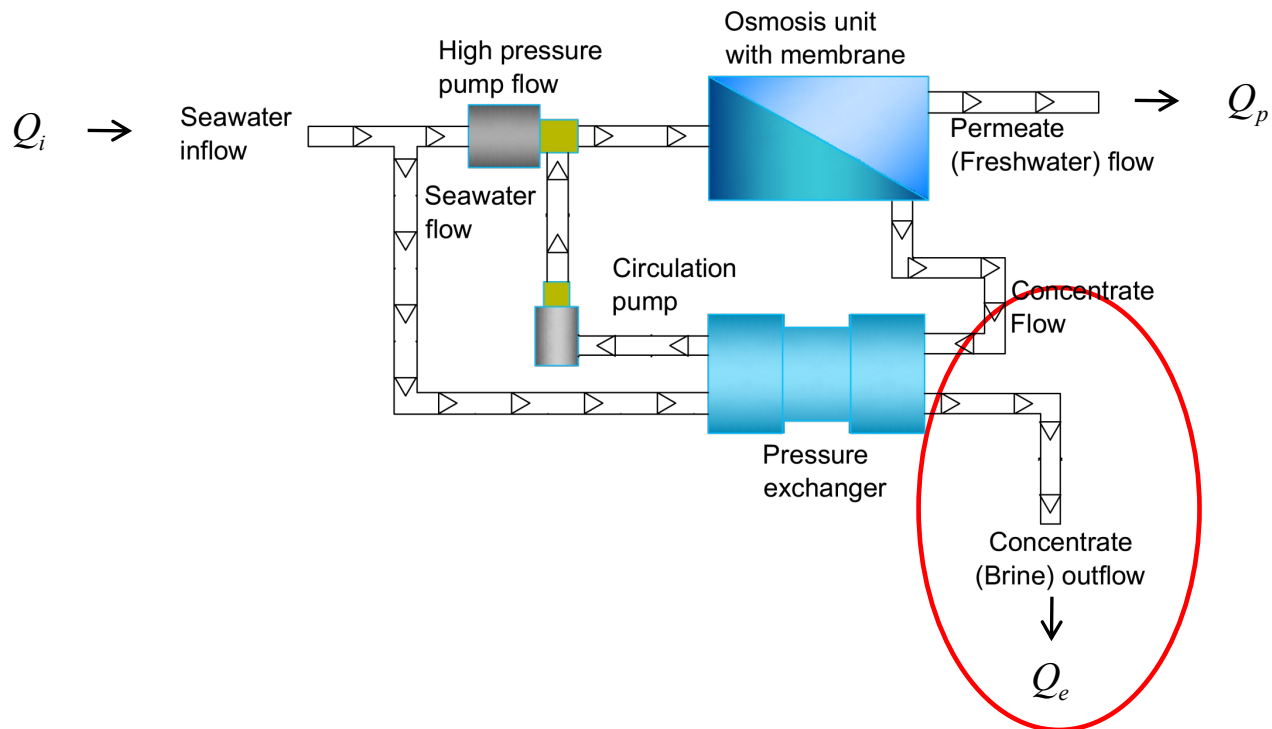


New desalination capacity 1980-2009



Applied Pressure  
(Greater than  
Osmotic Pressure)





# Effluent Flow Computations

Influent, Permeate and Brine Flow Rates

$$R_w = \frac{Q_P}{Q_i} \quad \text{and} \quad Q_i = Q_e + Q_P$$

or,  $Q_P = Q_i - Q_e$

where

$R_w$  = water recovery rate [-];

$Q_e$  = brine (concentrate ) flow rate [ $L^3T^{-1}$ ];

$Q_i$  = intake (feed) flow rate [ $L^3T^{-1}$ ];

$Q_P$  = permeate (fresh/produced) flow rate [ $L^3T^{-1}$ ].

Example:

$$Q_i = 2,000 \text{ gpm (0.1262 m}^3\text{/s);}$$

$$R_w = 50\%;$$

$$R_w = 1 - \frac{Q_e}{Q_i}$$

$$Q_e = Q_i (1 - R_w)$$

$$Q_e = 2,000 (1 - 0.5) = 1,000 \text{ gpm}$$

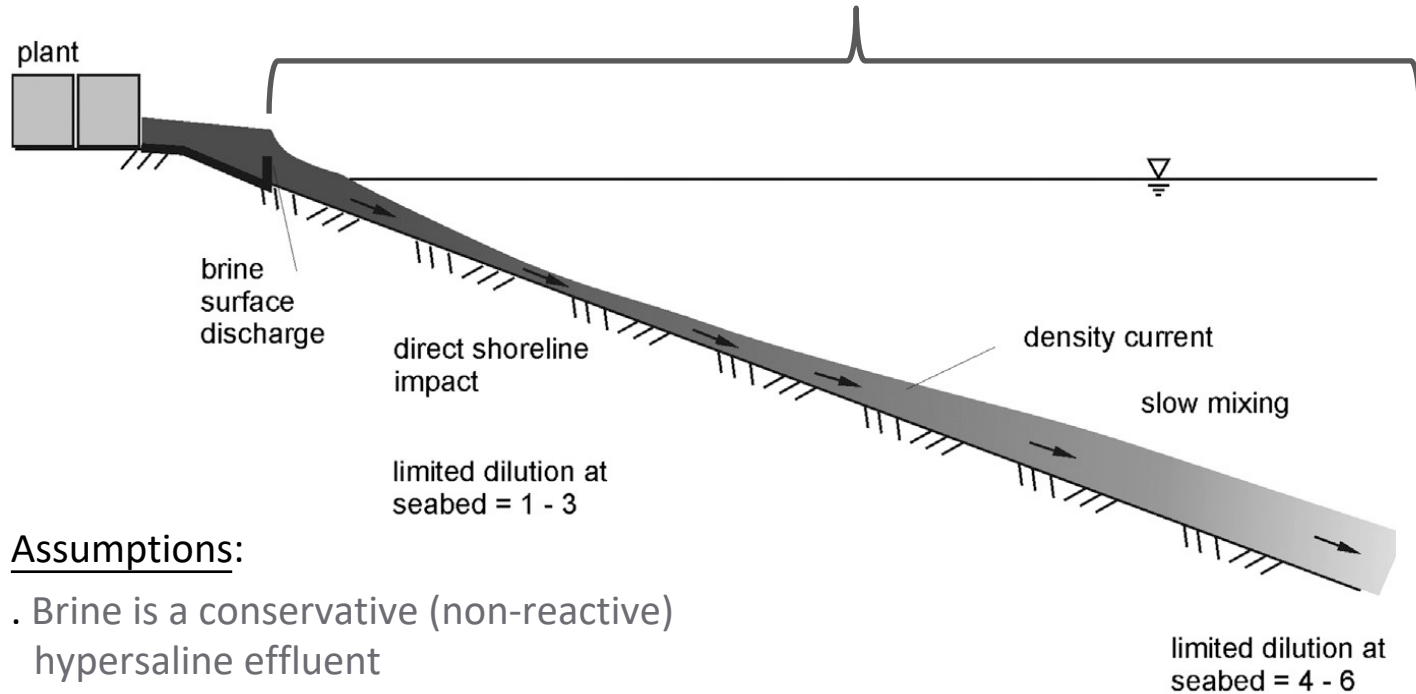
$$Q_e = 0.0631 \text{ m}^3\text{/s}$$

$$Q_p = 0.5 \times Q_i = 1,000 \text{ gpm (0.0631 m}^3\text{/s)}$$

$$\rho_e > \rho_a$$

$$\bar{S}_e \gg \bar{S}_a$$

## Impacts of surface discharge on coastal water quality



### Assumptions:

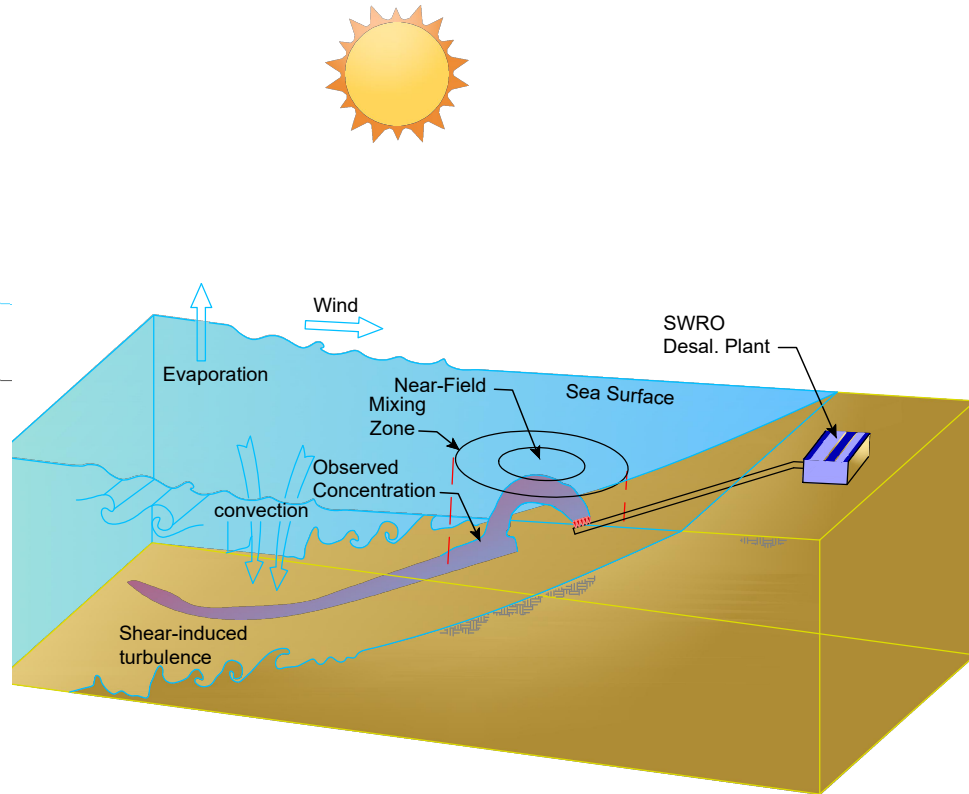
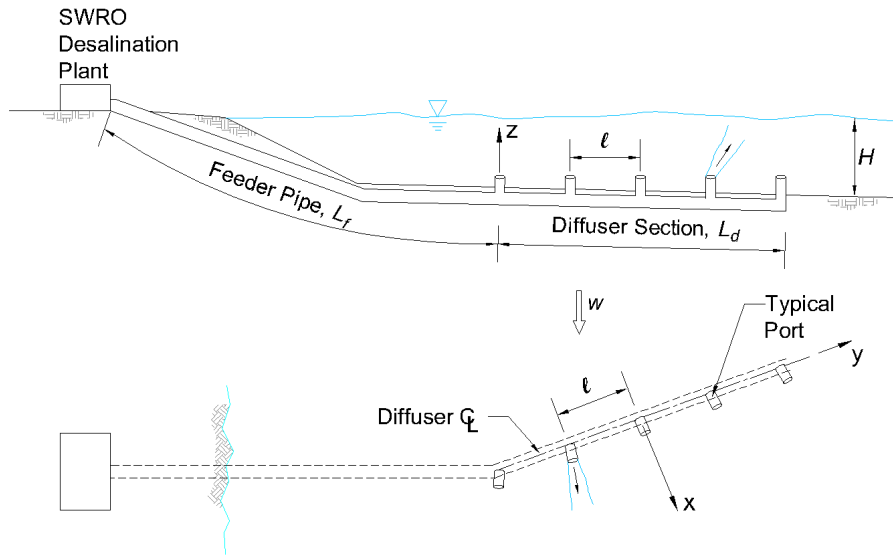
- . Brine is a conservative (non-reactive) hypersaline effluent
- . It is an incompressible, Newtonian fluid
- . Steady-state flow



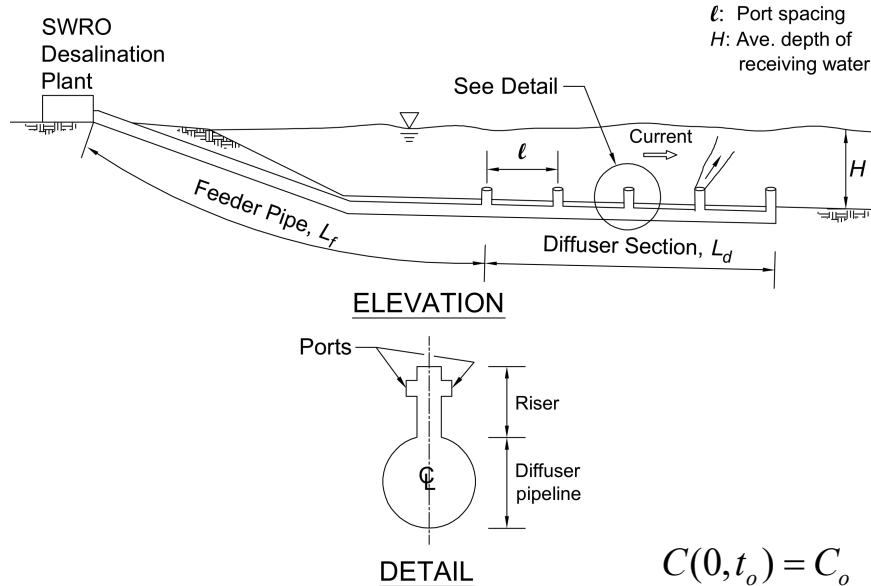
Surface discharge  
(Al Ghubrah Plant, Oman)

Surface discharge  
(Ashkelon Plant, during a  
backwash)

To minimize the impact...



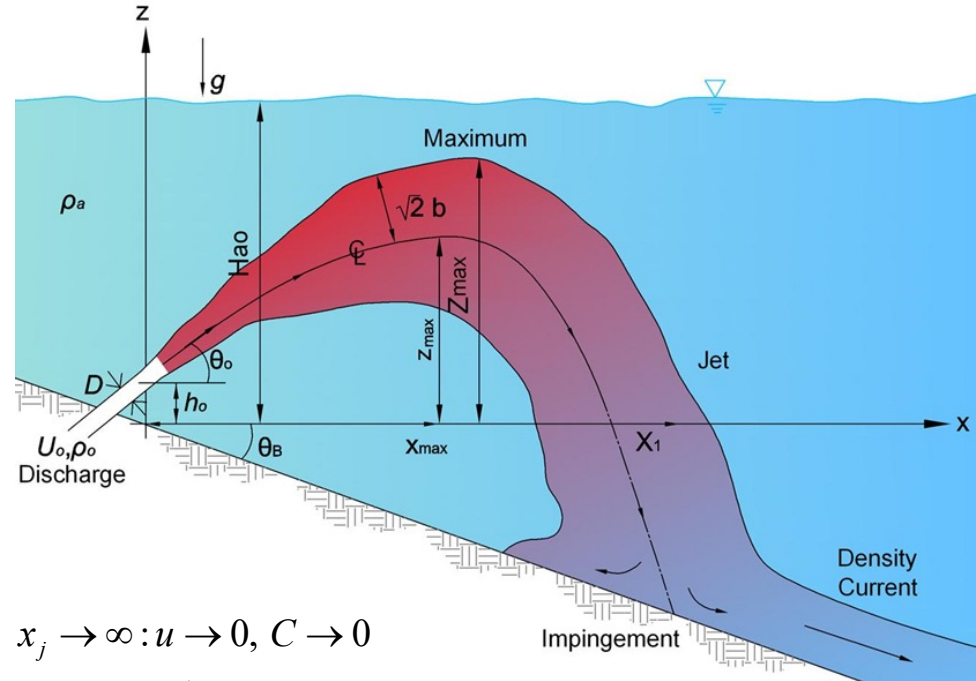
To minimize the impact...



$$C(0, t_o) = C_o$$

$$u(0, t_o) = u_o$$

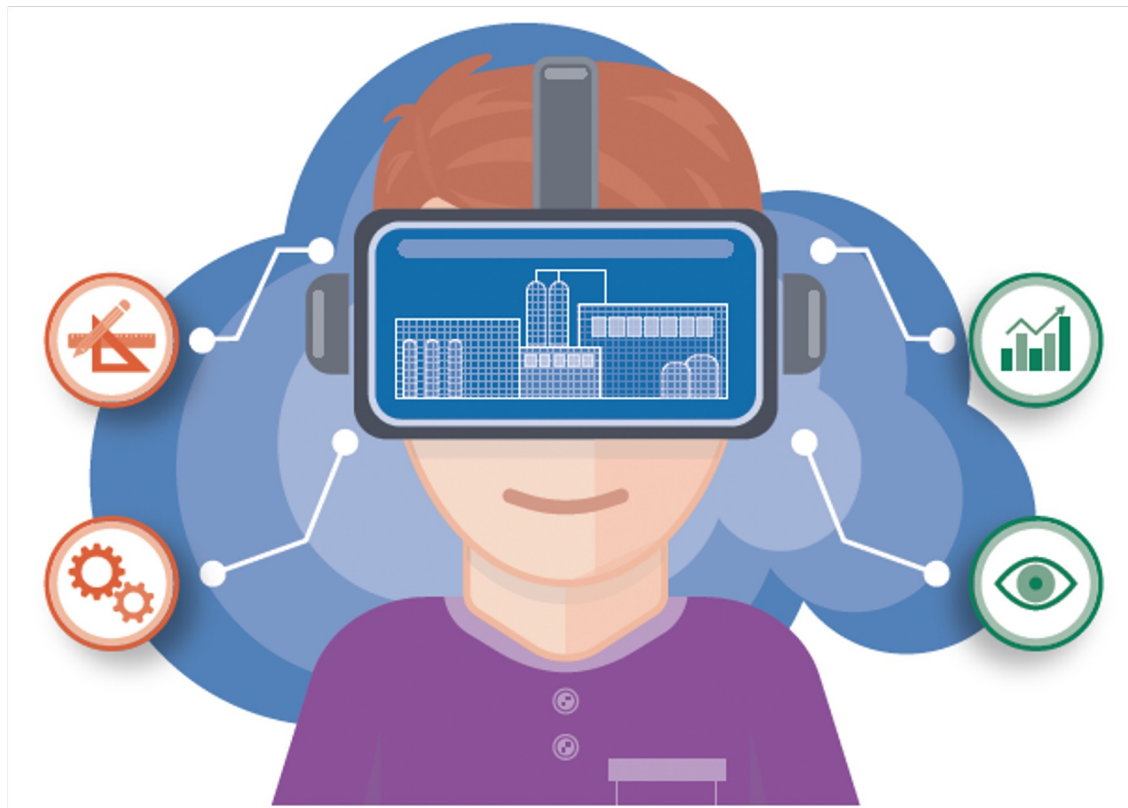
$$v(0, t_o) = v_o$$



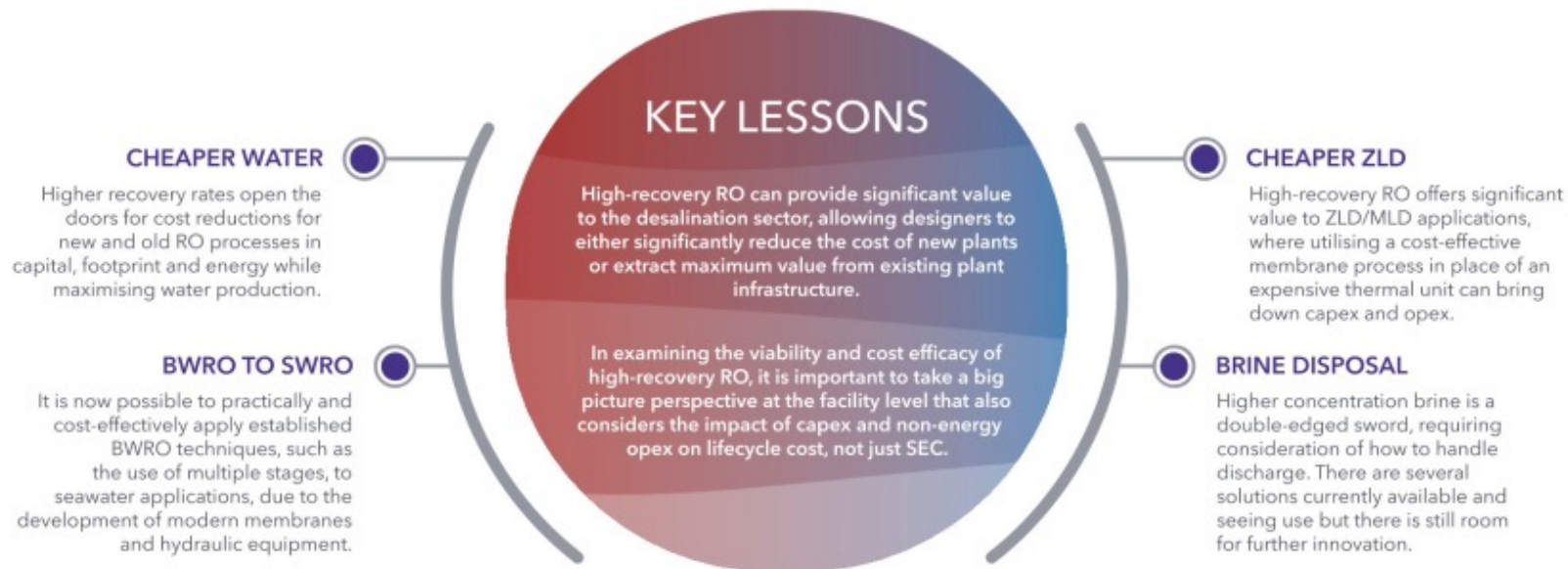
$$x_j \rightarrow \infty : u \rightarrow 0, C \rightarrow 0$$

$$\left. \frac{\partial C}{\partial x_j} \right|_B = 0$$





(Credit: GWI 2022)



(Credit: GWI 2022)

Minimize: Cost

Subject to:

- Initial Dilution (Length of Outfall, Pipe Diameter, Number of Ports, other drivers)
- Water Quality Constraints (Mixing Zone)

Area of mixing zone;  
Viability of chosen location;  
System reliability.

$$\text{Min } Z = w_1 L + w_2 D + w_3 N$$

Subject to: a. Initial Dilution

$$S \geq S_{rid}$$

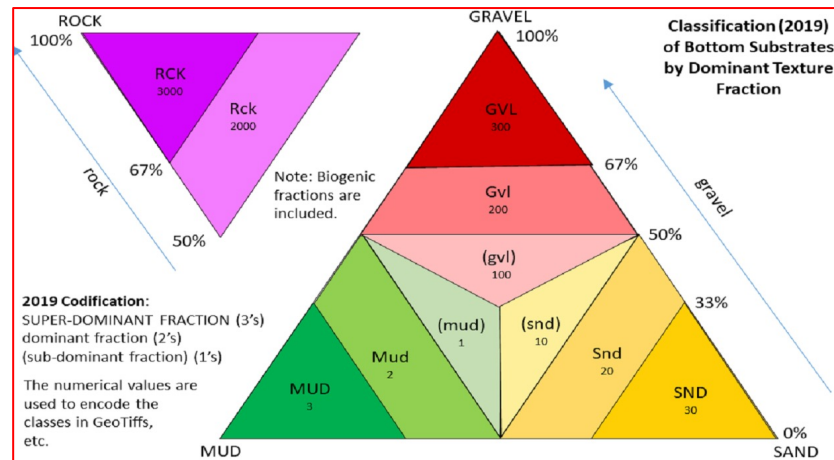
$$S = f(L, D, N, \dots)$$

$$S = f(x, \xi)$$

$$L_p^l \leq L_p \leq L_p^u \quad \forall p$$

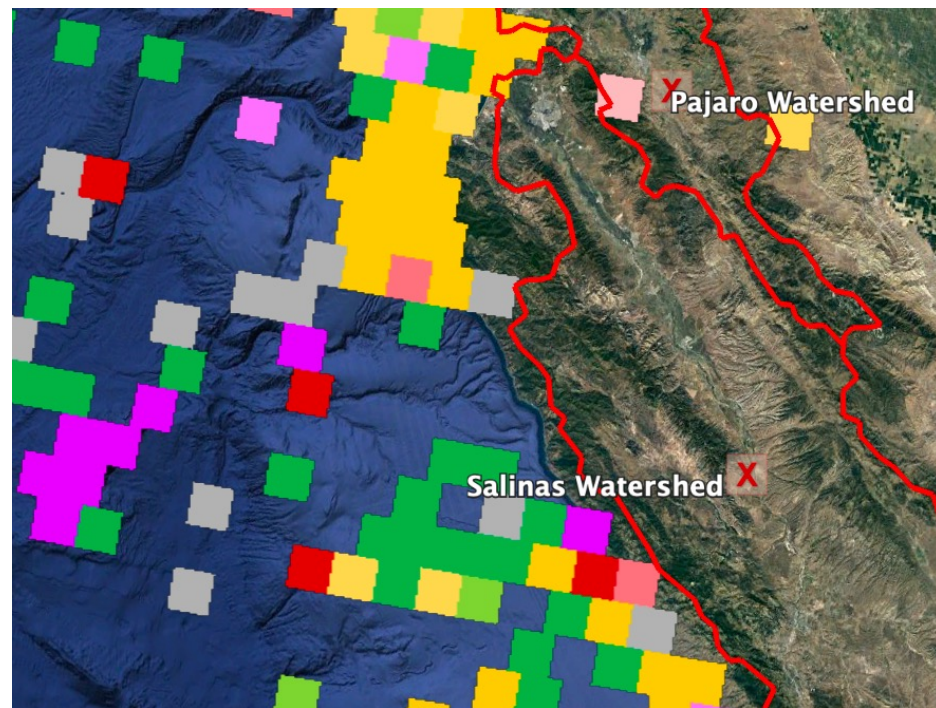
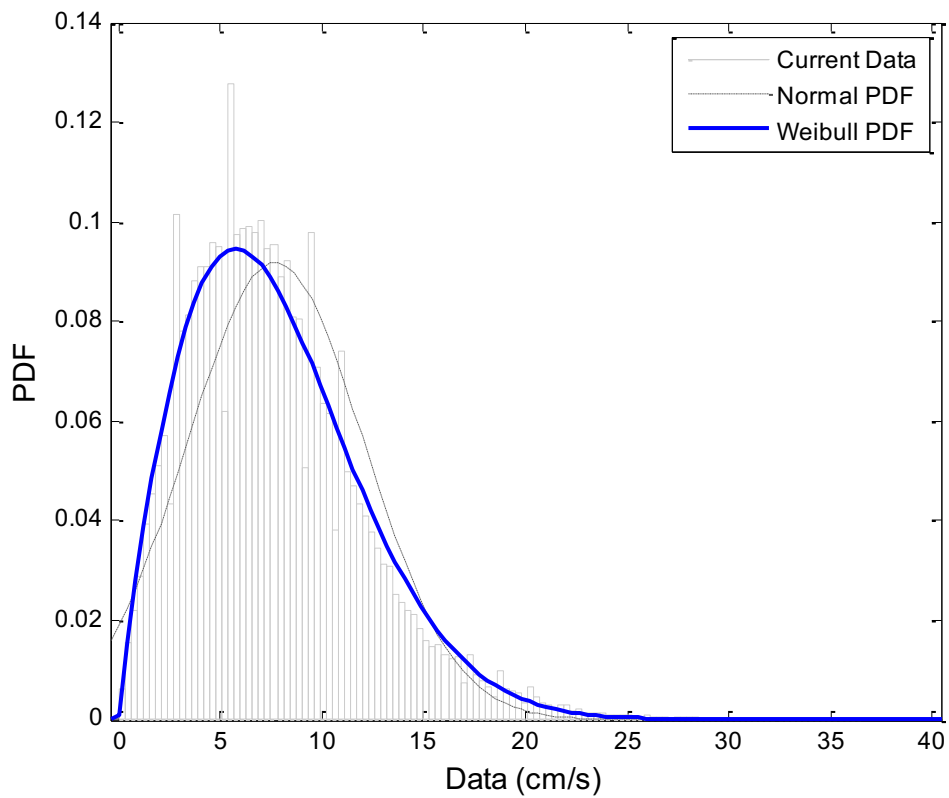
$$D_m^l \leq D_m \leq D_m^u, \quad m \in \mathbb{Z}^+$$

$$N_n^l \leq N_n \leq N_n^u, \quad n \in \mathbb{Z}^+$$



b. Water Quality Constraint

$$C_e \leq C_{rr}^{\max}$$



Initial Dilution:

$$S = f(x, \xi)$$

$$S = f(L, D, N, w, T, W \dots)$$

Current speed constraint:

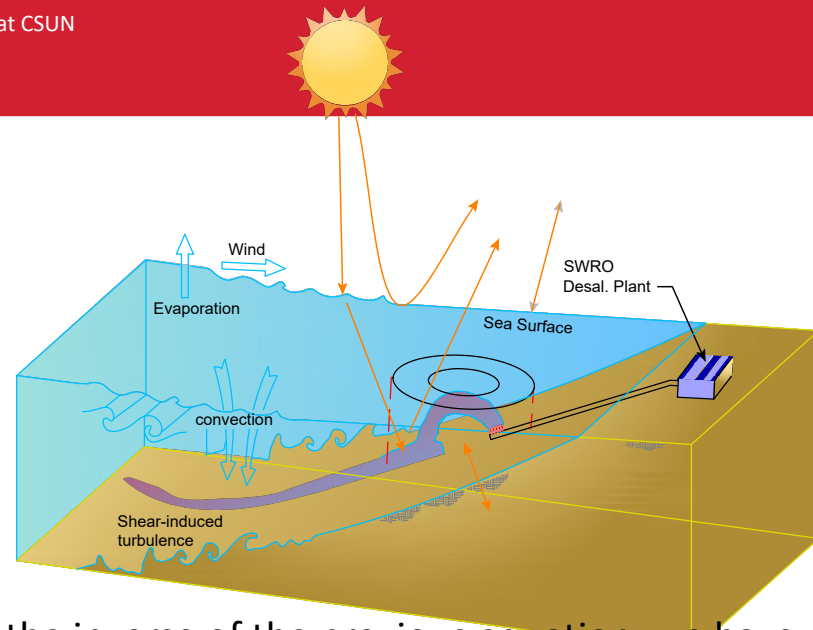
$$\Pr\{\bar{w}_i \leq \bar{w}_{\max_i}\} \geq \alpha_i, \quad \forall i$$

$$\alpha_i \in (0, 1), \quad \forall i$$

Deterministic equivalent:

$$F_\psi \left( \frac{w_i - E(w_i)}{[Var(w_i)]^{0.5}} \right) \geq \alpha_i$$

$$F_\psi \left( \frac{w_i - E(w_i)}{[Var(w_i)]^{0.5}} \right) \leq 1 - \alpha_i$$



Taking the inverse of the previous equation, we have:

$$w_i \leq E(w_i) + (F_\psi^{-1}(1 - \alpha_i)) [Var(w_i)]^{0.5}$$

Replacing  $w_i$  with  $\bar{w}_i$  we have:

$$\bar{w} = \bar{w}_{\max} - (F_\psi^{-1}(\alpha)) [Var(w)]^{0.5}$$